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DEVELOP AND TEST FUEL CELL POWERED ON-SITE INTEGRATED TOTAL ENERGY SYSTEMS: PHASE III, FULL-SCALE POWER PLANT DEVELOPMENT

18TH QUARTERLY REPORT: AUGUST - OCTOBER 1985

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NOTICE

SECTION I. INTRODUCTION

Engelhard's objective under the present contract is to contribute substantially to the national fuel conservation program by developing a commercially viable and cost-effective phosphoric acid fuel cell powered on-site integrated energy system (OS/IES). The fuel cell offers energy efficiencies in the neighborhood of 40% of the lower heating value of available fuels in the form of electrical energy. By utilizing the thermal energy generated for heating, ventilating, and air-conditioning (HVAC), a fuel cell OS/IES could provide total energy efficiencies in the neighborhood of 80%. Also, the Engelhard fuel cell OS/IES, which is the objective of the present program, offers the important incentive of replacing imported oil with domestically produced fuel.

Engelhard has successfully completed the first two phases of this program. The culmination of the pre-commercialization program will be the integration of the fuel cell system into a total energy system for multi-family residential and commercial buildings. The mandate of the current Phase III effort is to develop a full-scale 25kW breadboard power plant module. An accomplished objective in Phase III was the integration and testing of the 5kW system whose components were developed during Phase II. In addition to the development and testing of this sub-scale system, scale-up activities have been carried out under Phase III. Throughout this program, continuing technology development activity will be maintained to assure that the performance, reliability, and cost objectives are attained.

SECTION II. TECHNICAL PROGRESS SUMMARY

TASK I - 5kW POWER SYSTEM DEVELOPMENT

The objective of this task was to complete integration of the 5kW components and sub-systems developed during Phase II.

Steady-load testing of the 5kW integrated system, with regular shutdowns, was completed during August 1983. Subsequently, load-following testing was carried out successfully, as the system was operated in the fully-automatic mode. (See the August-October 1983 Quarterly Report.)

TASK II - ON-SITE SYSTEM APPLICATION ANALYSIS

The purpose of this task was to develop an application model for on-site integrated energy systems. The model considers fuel availability, costs, building types and sizes, power distribution requirements (electrical and thermal), waste heat utilization potential, types of ownership of the OS/IES, and grid connection vs. stand-alone operation. The work of this task was carried out under subcontract by Arthur D. Little, Inc. (ADL), and this work has been completed. The main conclusions are summarized in the May-July 1983 Quarterly Report.

TASK III - ON-SITE SYSTEM DEVELOPMENT

This task forms the core of the Phase III contract effort. Work under this task will result in the breadboard design of a system for an on-site application. The power plant is being designed for a rated output of 25kW (electrical). This task is broken down into four sub-tasks as follows:

III-1. Large Stack Development
III-2. Large Fuel Processor Development
III-3. Overall System Analysis
III-4. Overall System Design and Development

The activities under this contract are focusing on Sub-Task III-1. Effort on the other sub-tasks is being carried out under private sponsorship.

SUB-TASK 1. LARGE STACK DEVELOPMENT

A. LONG-TERM TEST STACKS

A key activity in the current program is long-term reliability testing of stacks incorporating state-of-the-art components and concepts. This effort will serve to verify their effectiveness and durability; alternatively, if problem areas (or potential problem areas) are exposed over the course of this program, modifications will be implemented as appropriate to attain long-term durability.

This phase has consisted of the construction, testing and evaluation of 4kW, 13 inch x 23 inch stacks. The first two stacks were essentially the same, each incorporating both the E-3 type and E-7 type of developmental cathode catalysts. Much of the testing utilized synthetic reformate fuel (75% H_2, 24% CO_2, 1% CO, moisturized to about 15% H_2O). These 25-cell stacks were shut down after operating for about 7000 and 8400 hours on load, respectively.

Stack No. 3 will contain 24 cells of the 13 inch x 23 inch size. Several new technology assessments will ensue from the testing of this stack. These include: (i) alternative bipolar plate B-element (separator) materials (polyetheretherketone and PFA Teflon) in comparison with polyethersulfone; (ii) new cathode catalyst types, including those on more corrosion-resistant supports; (iii) an alternative acid-transport layer configuration; and (iv) use of a single-component liquid coolant (triethylene glycol) in place of mineral oil. Also, the number of cells between cooling plates in this stack will be six instead of five.

After a delay caused by a required upgrading of the ventilation system for the hot-press, film-bonding operations for the bipolar plates were resumed during September and completed early in October. Downstream processing of the bipolar plates was also completed during October. All components and hardware were ready for stack assembly by the end of the month except for the coolant headers, which were undergoing rework.

B. 25kW STACK

The 25kW stack components are based primarily on those that were successfully employed in the first two 4kW (25-cell) stacks (above). Where appropriate in light of experimental results obtained on the smaller stacks, design modifications were implemented for the 25kW stack. These involved acid collection/drainage means to avoid corrosion at the bottom of the gas manifolds and a 0.0015 inch thick gold foil layer at the bottom current-collecting plate interface, also to avoid corrosion as well as the buildup of interfacial IR-loss.

The cells (175 of them, 13 inches x 23 inches) were stacked during May using cooling plates at the five-cell interval. After assembly of the stack hardware a light compressive load was applied. This was followed by completion of plumbing for the fuel, air, and coolant lines to and from the stack.

Completion of the acid-addition and compressive loading sequences was delayed into June by a series of unplanned stack heating system shutdowns (see below). When these tasks were accomplished, the reactant gas manifolds were fully tightened. For the most part the stack was sustained in the hot-standby mode during June (about 120°C; no load); however, interruptions in system operation caused many temperature cycles (to and from room-temperature) over the course of the month.

The stack was started on load in early July. The load was brought up gradually, as the cells appeared to be breaking in very slowly. Acid was added (and taken up) in piecemeal fashion as the stack's load and temperature were increased. Performance slowly improved during July and into August. Load was taken to 13kW at a stack voltage of about 97V with the temperature reaching 177°C. The results of diagnostic testing using both hydrogen and reformate fuel, however, suggest that cell damage occurred due to freeze-thaw cycles that were experienced prior to stack start-up.

C. 25kW SUPPORT SYSTEMS

Additional flexibility was built into the 25kW system during August. Electrical heating tapes were installed on the coolant lines to enhance the stack heat-up rate. Also,, a bank of hydrogen cylinders was installed for fuel use during diagnostic testing activities.

Operation of the methanol reformer showed a loss of methanol conversion efficiency during the early part of September. This was thought to have resulted from an inadvertent over-temperature condition that occurred during a start-up operation. The reformer catalyst was changed out during the latter part of September, and the catalyst was reduced in-situ.

Reformer operation was resumed at the start of October. However, the current catalyst charge showed signs of rapid deactivation. The methanol in the fuel storage tanks was analyzed and found to contain almost 1000 ppm of chlorinated hydrocarbons. The source of this contamination is being investigated.

The microprocessor computer hardware was also reworked during September in order to improve control system reliability. This activity included replacement of some components, resoldering of various electrical contacts, and application of protective resin coating to certain circuit boards.

TASK IV - STACK TECHNOLOGY

The purpose of this task, which will continue throughout the contract, is to investigate new materials and component concepts through bench-testing and stack trials. The criteria for selecting activities under this task are the prospects for improved performance, reduced costs, or improved reliability. Improvements in the performance of electrocatalysts, generated under Engelhard-sponsored Task VI, are reported under Task IV.

A. PERFORMANCE OPTIMIZATION

ALTERNATIVE ACID-TRANSPORT LAYERS

Additional evaluation of alternative acid-transport layers has been conducted in single-cells. This effort is directed toward reducing cell IR-loss as well as replacing the currently-used Kureha carbon fiber paper, which is no longer available in its present form. Further evaluation, however, is being carried out in stacks. This will facilitate meaningful assessment of alternative configurations by providing realistic conditions of compressive loading and acid replenishment as well as by allowing large areas of material to be tested at the same time.

A five-cell, 10.7 inch x 14 inch stack was constructed during October with an alternative acid-transport layer configuration (see Appendix). Generally encouraging results have been obtained thus far. Despite the fact that one cell is running well below par (reasons not yet apparent), the average cell voltage is 0.64V at 161mA/cm^2 and 191°C, H_2-air. The stack open-circuit voltage is quite high at 4.53V. The average cell IR-loss is about 40mV at 161 mA/cm^2.

This acid-transport layer configuration will be tested further in one six-cell sub-stack of the upcoming 4kW Stack No. 3.

The parallel activity involving the simple substitution of alternative carbon fiber materials for the Kureha paper (no longer available in its present form) that currently serves as the acid-transport layer has yielded results through single-cell testing. The IR-losses of two cells in which selected carbon fiber materials are being used (see May-July 1985 Quarterly Report) are about 10mV higher than that of a typical standard cell at normal operating conditions (i.e., about 55-60mV versus 45-50mV at 161 mA/cm^2). Also, open-circuit voltages are significantly lower than average. It appears that the two materials selected thus far will not be suitable substitutes for the Kureha material.

B. COST REDUCTION

NON-METALLIC COOLING PLATES

Design and experimental work have been conducted with larger diameter cooling tubes than the ones used on present stacks (3/8-inch i.d. vs. 1/4-inch i.d.) in order to cut back on the number of end-connections. This would eliminate two out of four end-connections per cooling plate. Performance and reliability tests on the tubes and end-connections at 200°C were successfully carried out to 70 psi. The design and fabrication of sample grooves that can accommodate the larger tubing were also accomplished.

Estimates of the production cost of corrugating the bends of the Teflon cooling tubes are being prepared with the help of a vendor.

CURRENT COLLECTORS

Corrosion testing of Engelhard-fabricated gold-clad base metal wire, the basis for a less expensive current-collecting plate, continues to show no sign of phosphoric acid penetration through the gold cladding after three months of immersion at 200°C.

A simulated one-ft^2 current-collecting plate of this type using all-copper 0.125-inch diameter wire (see Figure 1) was assembled and tested during September. The voltage drop was measured to be an acceptable 38mV at an equivalent current density of 150A/ft^2. Furthermore, the voltage drop would be significantly lower with the 8% (by weight) gold cladding, as per design.

C. RELIABILITY

CARBON SUPPORTS

The assessment of more corrosion-resistant cathode carbon support materials has shifted to Gulf Acetylene Black (GAB), which is intended as a replacement for the obsolete Shawinigan Black. A cathode using E-3 catalyst on GAB is being tested in a single-cell. This cell showed a peak performance of 0.711V IR-free (161mA/cm^2, 191°C, H_2-air) after about 600 hours, but it is evident that optimum electrode structure has not yet been achieved with this catalyst. Current performance is 0.684V (same conditions) after about 2000 hours.

LIFE-TESTING IN SINGLE-CELLS

A fixture in which the aluminum is replaced by Type 316 stainless steel has begun use in single-cell testing; this is expected to allow more meaningful long-term tests to be conducted without the complicating effects of fixture corrosion.

BIPOLAR PLATES

A comparison of long-term durability among polyethersulfone (PES), polyetheretherketone (PEEK), and PFA Teflon bipolar plate B-elements will be obtained through the testing of 4kW Stack No. 3 (see above), which contains all three types. Corrosion tests for the three candidate B-element materials were carried out as shown in Figure 2. While the corrosion currents at 0.9V (versus RHE) were quite similar, the Tafel slope for PFA was far lower than those for PES and PEEK, as shown in Table I. Therefore, the corrosion rate for PFA at typical fuel cell cathode potential (about 0.7V vs. RHE) would be substantially lower.

Previous electrical testing of bipolar plates required that, to obtain reliable data on the distribution of through-plane electrical resistance (i.e., across the B-element of an ABA plate), it be divided into small segments for individual testing of local areas. Testing of plates with metallic contacts covering their entire surfaces does not correctly simulate the current distribution in a stack; stack current densities are much more uniform than those generated by equipotential contacts.

A more meaningful test has been devised which forces essentially equal amounts of current through each 2 inch x 2 inch region of any unsegmented plate, using the circuit and the physical arrangement shown in Figures 3 and 4, respectively. Voltage probes directly contact the two surfaces across any region of the plate, yielding the desired data on local variations in B-element resistance. The plate tester is being used to retest unused plates and to analyze used plates from dismantled stacks; the tester can also serve in production quality control. Tests carried out thus far indicate that care must be taken to provide a uniform film-bonding temperature. The hot-press has now been equipped with thermal insulation and additional heating elements to insure such uniformity.

DRY FIVE-CELL STACK

A dry five-cell stack (10.7 inches x 14 inches) was built to test the feasibility of acid-filling after assembly. After this stack was preheated to 215°F, 105% H_3PO_4 was added to each individual cell through the acid-reservoir wicks and Kureha paper (acid-transport layer) shelves. The rate of acid uptake by the stack is illustrated in Figure 5. This indicates that the total acid uptake essentially reached the level that would have been charged during stack assembly in a standard construction. Load was introduced when the acid uptake reached approximately 80% of this level.

The stack was run for about 500 hours on load. Over the first 350 hours the stack was run with hydrogen fuel, and the average cell voltage was approximately 0.64V (161mA/cm^2, 191°C), quite similar to what is typical for standard stack construction (as is the average open-circuit voltage of 0.86V per cell). The remainder of the test was carried out with simulated reformate fuel (1% CO, 24% CO_2, 75% H_2) at a hydrogen utilization rate of 80%. The average H_2-gain was 28mV; this is a few millivolts higher than typical, and it is attributed to several hours of hot, no-load exposure as the result of a house power failure. These results are encouraging, suggesting that far greater flexibility is feasible in the assembly and transport of fuel cell stacks.

TASK V - FUEL PROCESSING SUPPORT

The intent of this task was to provide background data and information to support the design and construction of an optimized 50kW fuel processor under Task III. Most of the effort of this task was devoted to screening and longevity testing of catalysts for steam-reforming of methanol. This task is now complete.

TASK VI - IMPROVED ELECTROCATALYSTS

Developmental electrocatalyst formulations are being prepared under Engelhard sponsorship. These are provided to the main program, and results are reported under Task IV.

Development is being pursued on both cathode and anode catalysts and supports; however, the major activity at the present time is directed toward improved cathode stability and activity (see Task IV).

SECTION III - CURRENT PROBLEMS

- Source of methanol feed contamination in 25kW system to be identified and eliminated.

SECTION IV - WORK PLANNED

TASK III - ON-SITE SYSTEM DEVELOPMENT

- Find and eliminate source of contamination in feed for methanol reformer.
- Initiate testing of 4kW Stack No. 3.

TASK IV - STACK TECHNOLOGY

- Continue evaluation of alternative acid-transport layers in stacks.

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TABLE I

Tafel Slopes for Bipolar Plate B-Element Materials after 1000-Min Test

Test Conditions: 0.9V versus RHE
400°F (204°C)
105% $H_3PO_4(N_2)$

Material	Tafel Slope (mV/Decade)
PEEK/750°F	285
PES/700°F	275
PFA/700°F	184

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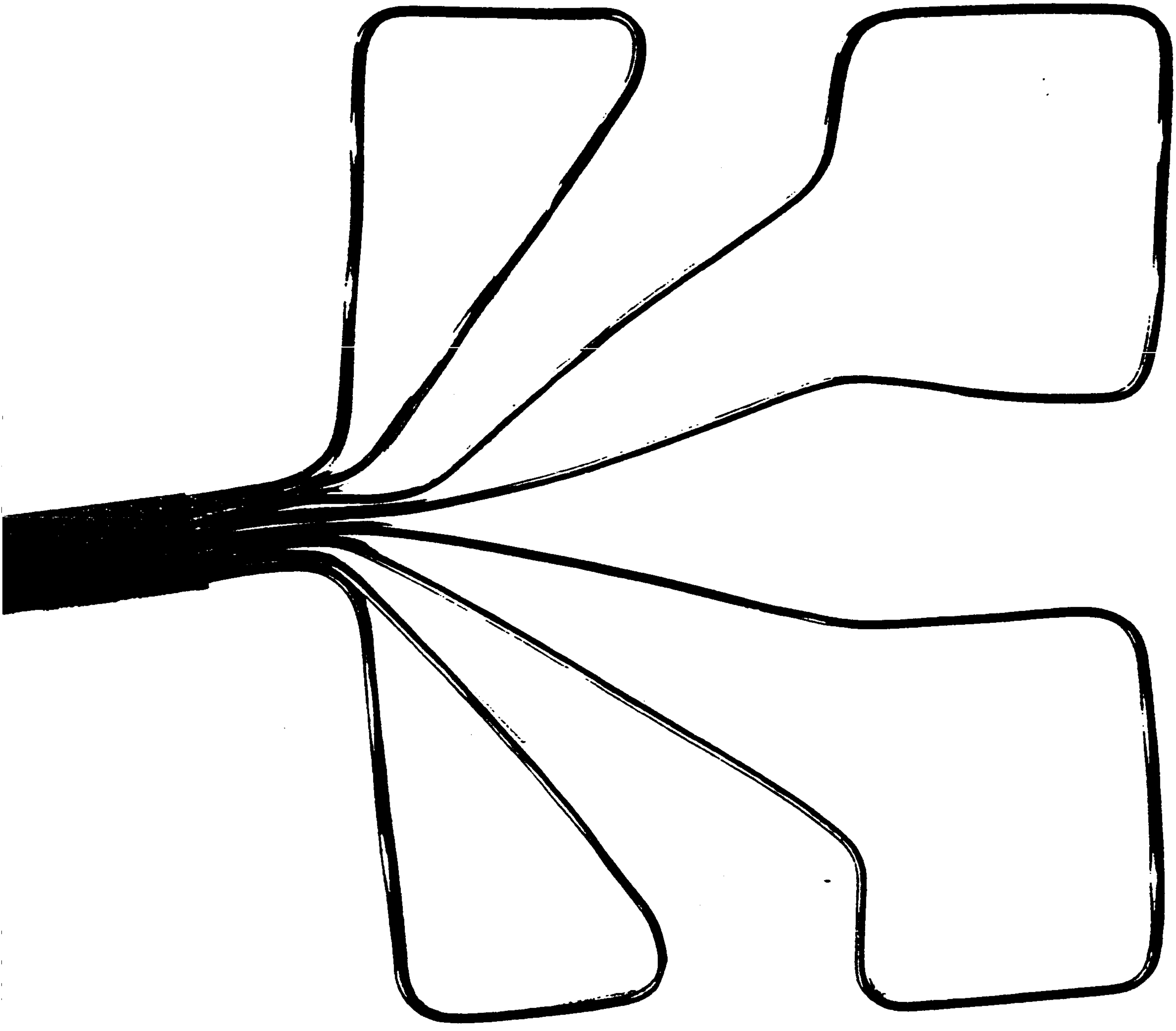

FIGURE 1 GOLD-CLAD WIRE CURRENT COLLECTOR CONCEPT

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OF POOR QUALITY

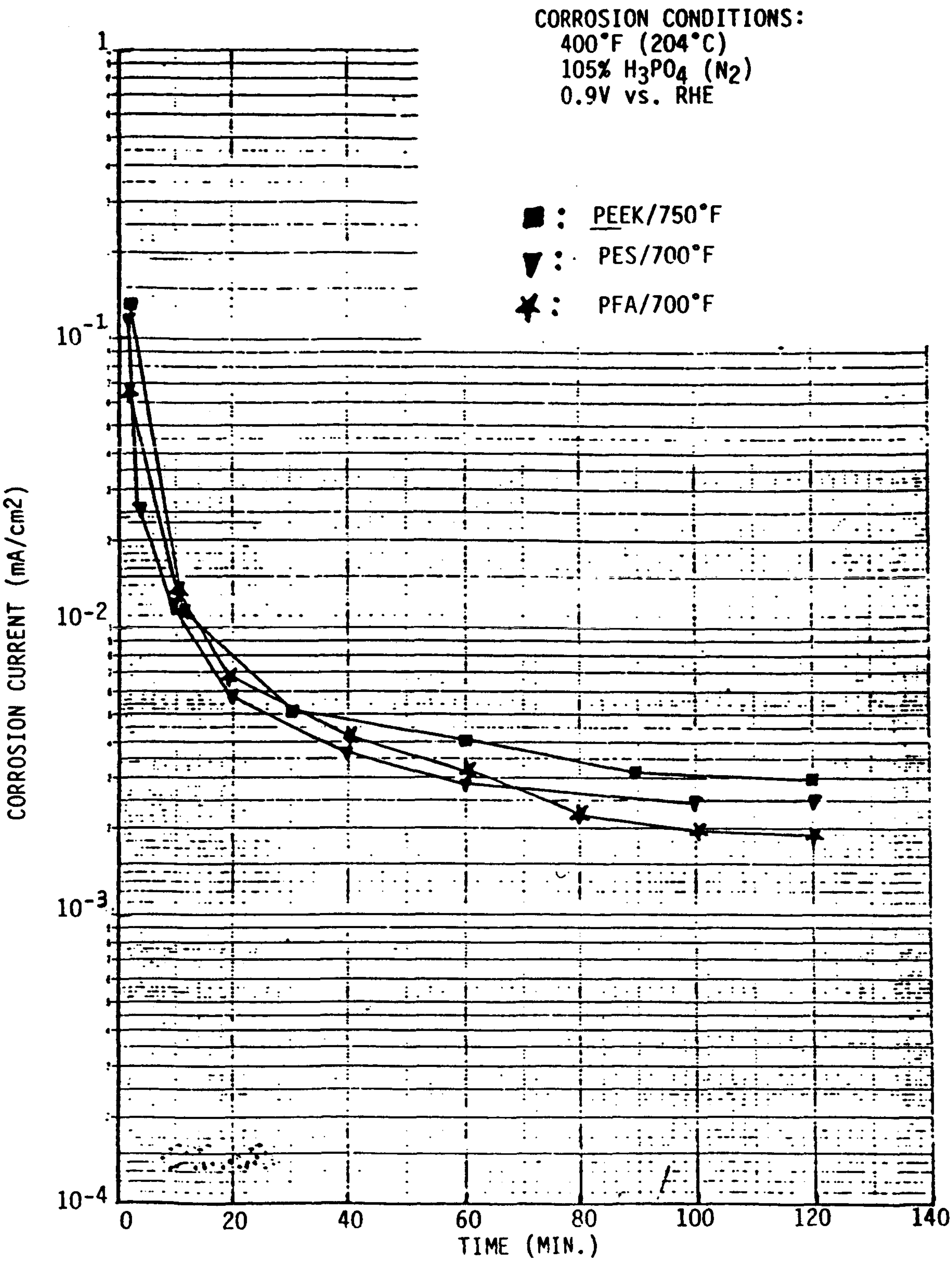

FIGURE 2 CORROSION CURRENT OF B-ELEMENTS

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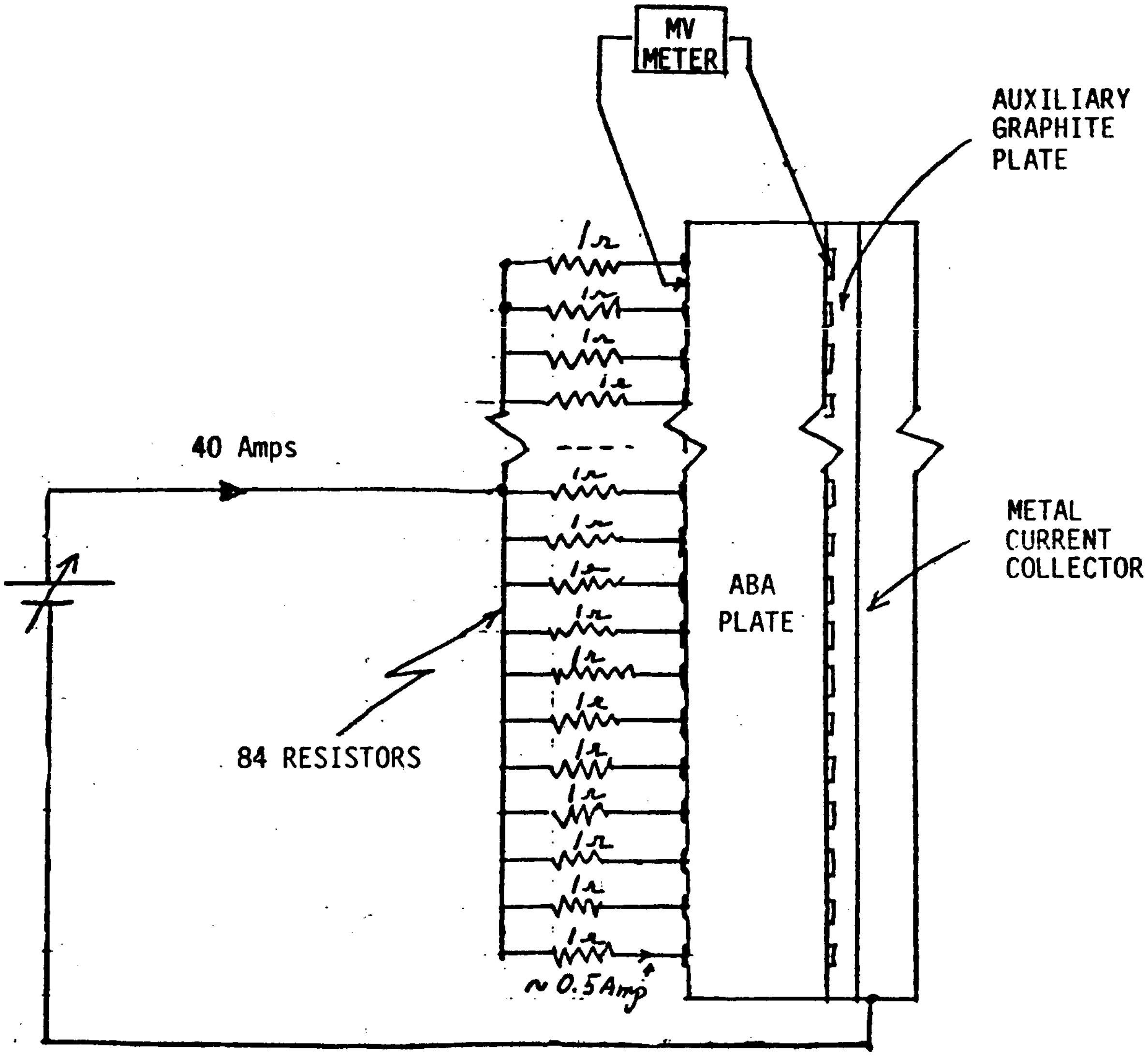

FIGURE 3 TEST CIRCUIT FOR ABA PLATES

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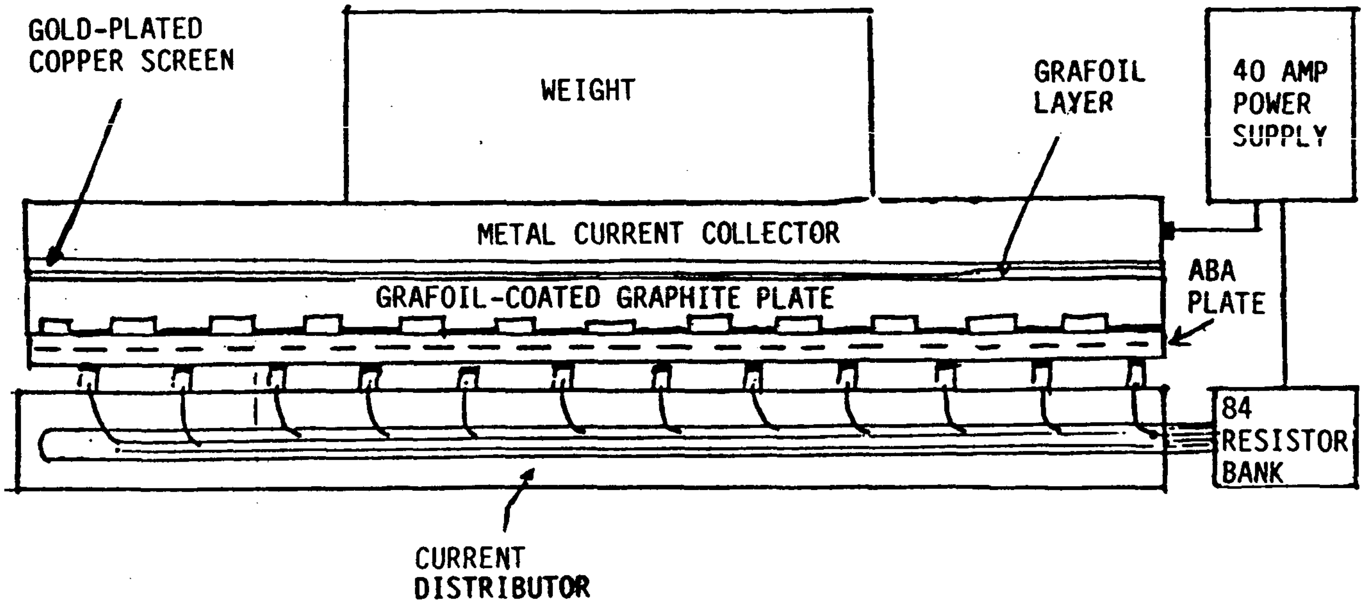

FIGURE 4 ELECTRICAL TEST FIXTURE FOR ABA PLATES

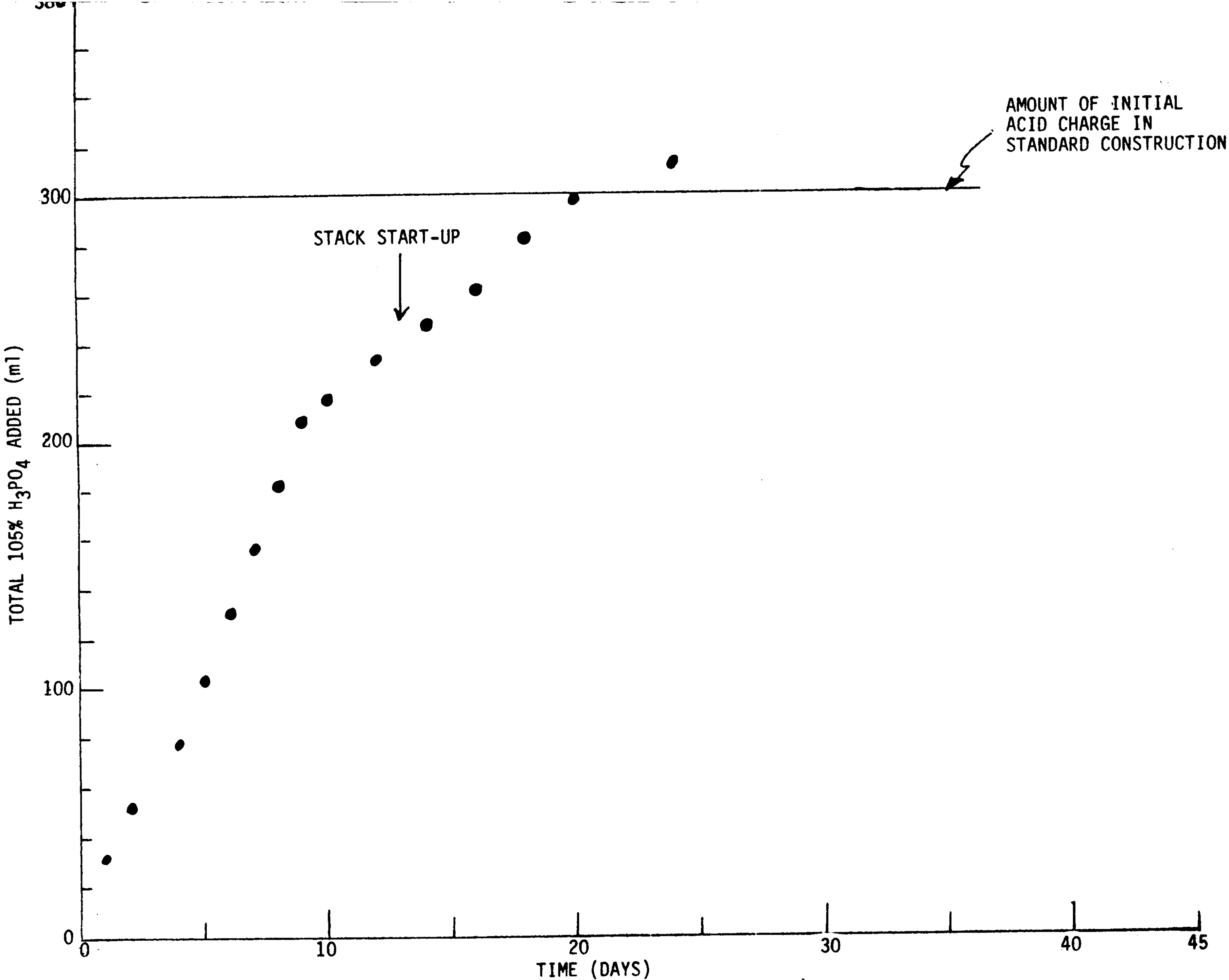

FIGURE 5 ACID UPTAKE OF "DRY" FIVE-CELL STACK (10.7 IN. X 14 IN.)

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15. Supplementary Notes

16. Abstract

The testing of two 25-cell stacks of the 13 inch x 23 inch cell size (about 4kW) was carried out for 7000 and 8400 hours, respectively. A 25kW stack containing 175 cells of the same size and based on the same technology was constructed and is on test. A third 4kW stack, which will contain 24 cells, will comprise several new technology features; these will be assessed for performance and durability in long-term testing.

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